The Analysis of Time Acceleration and Productivity of New Shipbuilding Project

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ABSTRACT

This study aims to develop a project schedule for the X1 tugboat construction at PT XYZ using the Critical Chain Project Management (CCPM) method to accelerate completion time, improve labor productivity, and evaluate changes in direct labor costs. The direct observation and interviews were conducted to collect data on the work breakdown structure, activity durations, work volume, workforce size, and daily wages. This study applies Critical Chain Project Management (CCPM) to the X1 tugboat construction project at logistic and shipping company to develop a faster schedule, improve labor productivity, and evaluate direct labor costs. CCPM reduces safety time and centralizes the resulting buffer at the project level. With safety time reduced by 50%, the proposed schedule shortens project duration by 39.35%, increases productivity from 1 to 2/ Mondays, and increases direct labor costs by 0.14%.

Keywords: critical chain project management, scheduling, productivity, new ship construction, time acceleration

A. Introduction

Indonesia, as the world's largest archipelagic country, has substantial potential for marine-resource utilization. The shipbuilding industry plays an important role in supporting maritime transportation and meeting demand for vessels (Firmansyah & Djafar, 2018; Istiqomah et al., 2021). New shipbuilding is therefore a fundamental production activity in the maritime industry (Diswantoro, 2024).

Shipbuilding projects have defined activities, schedules, resources, and completion targets (Rizcola et al., 2019). However, material-flow mismatches, production scrap, limited equipment, and other field constraints can disrupt planned activities and delay completion (Riyadi, 2018; Ersaputra et al., 2022). A delay in one activity may affect the entire project and other projects that depend on the same production facilities. Under Presidential Decree No. 16 of 2018, delays may also result in a penalty of 1‰ of the contract or contract-package value for each day of delay (Amalia Putri et al., 2024).

Efficient project management is needed to reduce the risk of delay in new shipbuilding. One approach is Critical Chain Project Management (CCPM), which integrates resource constraints and buffer management into project scheduling and supports timely project completion (Fahmi et al., 2023). This study focuses on applying CCPM to a new shipbuilding project at PT XYZ that exceeded its agreed contract duration. PT XYZ is a logistics and shipping company established in 1976. Its activities have expanded from ship repair to ship modification and new ship construction for external customers, while maintaining quality and safety standards.

Project management must balance

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scope, time, cost, and quality. Project success depends on completing the required scope with appropriate quality while managing available resources and implementation time (Abdurrasyid et al., 2019; Soeharto, 1999). Effective management of project resources is therefore necessary to maintain productivity and achieve organizational targets (Pratama, 2023).

CCPM was introduced by Eliyahu M. Goldratt as an application of the Theory of Constraints (TOC). It focuses on the overall project rather than optimizing individual activities. CCPM reduces activity-level safety time and places protection in project and feeding buffers (Aulady & Orleans, 2016; Sudarminto & Mulyatno, 2020). Project buffers protect the completion date, while feeding buffers protect the critical chain from delays on non-critical paths (Sreenivas Padala et al., 2023).

Based on this background, the study identifies three main problems: (1) the new shipbuilding project exceeds the planned contract duration; (2) labor productivity is not optimal across project activities; and (3) project delays may increase direct labor costs. Previous studies have shown that CCPM can shorten project duration and improve productivity. Tarigan (2019), for example, reported a 91-day CCPM schedule compared with a 105-day contract duration. Musfar et al. (2023) also found that a 50% reduction in safety time shortened project duration, increased labor productivity, and reduced project costs.

This study therefore analyzes project-duration acceleration, labor productivity, and direct labor costs using CCPM. The research questions are (1) How does the total duration under CCPM compare with the initial project duration? (2) How do direct labor costs under CCPM compare with the initial costs? and (3) How does labor productivity under CCPM compare with productivity under the initial project schedule?

The study aims to develop a CCPM-based project schedule that accelerates completion, improves labor productivity, and evaluates changes in direct labor costs.

B. Methods

1. Location and Object of Research

This study was conducted at PT XYZ in Central Java using the Critical Chain Project Management (CCPM) approach. The research object was a new shipbuilding project involving the X1 tugboat. Data were collected through direct observation and interviews with PT XYZ. The data included the work breakdown structure, work volume, labor costs, number of workers, and activity duration. A literature review was also conducted to provide the theoretical basis for the analysis.

Unlike methods that assign safety time to individual activities, CCPM manages uncertainty through centrally placed buffers. In this study, the safety time for each activity was reduced by 50% to obtain the CCPM duration. Slack is the amount of time an activity can be delayed without affecting the overall project schedule (Soeharto, 1999). It is calculated using Equations 1 and 2.

$$slack = LF - EF \quad (1)$$
$$slack = LS - ES \quad (2)$$

Reducing activity durations in CCPM increases exposure to schedule variability. Buffer time is therefore used to absorb potential delays and protect the planned completion date. In this study, buffer size was calculated using the Root Square Error Method (RSEM), based on safe duration (S) and CCPM duration (A), as shown in Equation 3.

$$2\sigma = 2\sqrt{\left(\frac{S1-A1}{2}\right)^2 + \left(\frac{S2-A2}{2}\right)^2 + \cdots + \left(\frac{Sn-An}{2}\right)^2} \quad (3)$$

Labor productivity is an important indicator of project performance because it reflects the amount of output achieved with available labor and time. Changes in productivity can indicate operational problems that require evaluation (Wahyuni, 2017;

Table 1 Reduction of Activity Duration

ID	Work Activities	Safe Duration (Days)	CCPM Duration (Days)
A1	Lines Plan	7	3,5
A2	General Arrangement	10	5
A3	Construction Profile & Midship Section	7	3,5
A4	Shell Expansion	9	4,5
A5	Frame Section	10	5
A6	MTO (Material Take Off)	8	4
B1	Procurement of Plate Requirements	60	30
B2	Procurement Machinery	90	45
B3	Procurement Electrical System	90	45
B4	Procurement Piping System	60	30
B5	Procurement Navigation & Communication System	60	30
B6	Procurement of Safety Equipment	30	15
B7	Procurement of Needs Interior & Exterior	30	15
C1	Making Nesting Plan	14	7
C2	Cutting Plate Requirements (With CNC)	120	60
C3	Process Sub Assembly	50	25
C4	Process Assembly	60	30
C5	Block Erection	90	45
D1	Process Keel Laying	1	0,5
E1	Installation Main Engine	7	3,5
E2	Installation Auxiliary Engine	10	5
E3	Propulsion Installation	5	2,5
E4	Installation Rudder	5	2,5
E5	Installation Navigation & Communication System	5	2,5
E6	Safety Equipment Installation	5	2,5
E7	Installation Requirements Interior And Exterior	14	7
F1	Pump Installation – Pumps	30	15
F2	Installation Piping System	60	30
F3	Installation Electrical System	60	30
G1	Pump Testing	5	2,5
G2	Testing Piping System	5	2,5
G3	Testing Electrical System	5	2,5
G4	Hull Welding Testing	12	6
G5	Tank Tightness Testing	8	4

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ID	Work Activities	Safe Duration (Days)	CCPM Duration (Days)
G6	Window & Door Tightness Testing	5	2,5
G7	Inclining Test	3	1,5
G8	Dock Trial	3	1,5
G9	Sea Trial	1	0,5
G10	Testing Bollard Pull	2	1
H1	Launching	7	3,5
H2	Ship Handover	3	1,5

Siregar et al., 2025). Labor productivity was calculated using Equation 4.

$$\text{Productivity} = \frac{\text{Work Volume}}{\text{Time x Labor}} \quad (4)$$

Direct labor costs are costs associated with workers directly involved in production activities, including workers who operate equipment or production facilities (Suwasono et al., 2024). In this study, direct labor costs were calculated from labor wages, workforce requirements, and activity duration using Equation 5.

$$Cost = UTK \; x \; TK \; x \; D \quad (5)$$

Information:
TK: Workforce (people).
TK : Workforce (People)

The collected data were used to calculate project duration, labor productivity, and direct labor costs. Data processing began by constructing the project network from the work breakdown structure, reducing safety time by 50%, calculating project and feeding buffers, and conducting buffer management analysis. The CCPM results were then compared with the initial project schedule.

The previously collected data will be used to identify issues that arise in calculating total work duration, labor costs, and worker productivity during the new shipbuilding project at PT XYZ. Data processing begins with the creation of a work network using the CCPM method based onwork breakdown structure research reference vessel, eliminating safety time in scheduling with the CCPM method, it provides project buffer And feeding buffer, conduct analysis buffer management. Calculation of productivity, direct labor costs, and project scheduling using the CCPM method will be subjected to comparative analysis at the initial project duration conditions.

C. Results and Discussion

1. Reducing Activity Duration

The first step in applying CCPM was to reduce the duration of each activity by 50% from its original safe duration. This approach reduces activity-level safety time and addresses behavioral effects such as student syndrome and Parkinson's Law, in which available time can influence task completion (Faiizuddaroini et al., 2022). The resulting CCPM durations are presented in Table 1.

2. Network Creation

After establishing the predecessor and successor relationships, forward calculations were performed to determine Early Start (ES) and Early Finish (EF) for each activity. The results are presented in Table 2.

After the forward calculation, a backward calculation was performed to determine Latest Start (LS) and Latest Finish (LF), as presented in Table 3.

For activity H2, the backward calculation

gives an LS of 257.5 days and an LF of 259 days.

3. Determining the Critical Path.

After ES, EF, LS, and LF were calculated, total float was determined to identify the critical path. Activities with zero total float form the critical path.
The activities with zero total float are G7, G8, G9, G10, and H2. Thus, the critical path is G7–G8–G9–G10–H2.

4. Determine Feeding Buffer

The feeding buffer protects the critical chain from delays originating on non-critical paths. For this project, the feeding buffer was calculated from selected non-critical activities, as shown in Table 5.

5. Determine Project Buffer

The project buffer is placed at the end of the critical chain to protect the planned completion date from delays on critical activities. The calculation is presented in Table 6.

The calculated project buffer is 2.82 days. With the 50% safety-time reduction and the project buffer, the CCPM schedule gives a total project duration of 262 days.

Table 2 Results of Forward Rate Calculation

ID	Work Activities	CCPM Duration (Days)	Forward Calculation	
			LS	LF
A1	Lines Plan	3,5	0	3,5
A2	General Arrangement	5	3,5	8,5
A3	Construction Profile & Midship Section	3,5	8,5	12
A4	Shell Expansion	4,5	12	16,5
A5	Frame Section	5	16,5	21,5
A6	(Material Take Off)	4	21,5	25,5
B1	Procurement of Plate Requirements	30	25,5	55,5
B2	Procurement Machinery	45	25,5	70,5
B3	Procurement Electrical System	45	25,5	70,5
B4	Procurement Piping System	30	25,5	55,5
B5	Procurement Navigation & Communication System	30	25,5	55,5
B6	Procurement of Safety Equipment	15	25,5	40,5
B7	Procurement of Needs Interior & Exterior	15	25,5	40,5
C1	Making Nesting Plan	7	21,5	28,5
C2	Cutting Plate Requirements (With CNC)	60	55,5	115,5
C3	Process Sub Assembly	25	115,5	140,5
C4	Process Assembly	30	140,5	170,5
C5	Block Erection	45	170,5	215,5
D1	Process Keel Laying	0,5	215,5	216,5
E1	Installation Main Engine	3,5	250,5	254

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ID	Work Activities	CCPM Duration (Days)	Forward Calculation	
			LS	LF
E2	Installation Auxiliary Engine	5	215,5	220,5
E3	Propulsion Installation	2,5	254	256,5
E4	Installation Rudder	2,5	256,5	259
E5	Installation Navigation & Communication System	2,5	215,5	218
E6	Safety Equipment Installation	2,5	215,5	218
E7	Installation Requirements Interior And Exterior	7	250,5	257,5
F1	Pump Installation - Pumps	15	215,5	230,5
F2	Installation Piping System	30	215,5	245,5
F3	Installation Electrical System	30	220,5	250,5
G1	Pump Testing	2,5	230,5	233
G2	Testing Piping System	2,5	245,5	248
G3	Testing Electrical System	2,5	250,5	253
G4	Hull Welding Testing	6	215,5	221,5
G5	Tank Tightness Testing	4	221,5	225,5
G6	Window & Door Tightness Testing	2,5	257,5	260
G7	Inclining Test	1,5	253	254,5
G8	Dock Trial	1,5	254,5	256
G9	Sea Trial	0,5	256	256,5
G10	Testing Bollard Pull	1	256,5	257,5
H1	Launching	3,5	225,5	229
H2	Ship Handover	1,5	257,5	259

6. Analysis Buffer Management

Buffer management monitors the consumption of the project buffer rather than tracking every activity independently (Sugiyanto, 2021). The green zone indicates that the project is under control. The yellow zone indicates that potential problems require attention, while the red zone indicates that corrective action is needed to protect the schedule (Bahnas et al., 2024).

The project buffer is 2.82 days and is divided into three equal zones to determine the buffer-consumption thresholds shown in Table 9.

7. CCPM Scheduling Work Productivity

Labor productivity for the X1 tugboat project was assessed using work volume, activity duration, and workforce size. Because

Table 3 Results of the Backward Rate Count

ID	Work Activities	CCPM Duration (Days)	Countdown	
			LS	LF
A1	Lines Plan	3,5	2,5	1
A2	General Arrangement	5	1	6
A3	Construction Profile &	3,5	6	9,5

ID	Work Activities	CCPM Duration (Days)	Countdown	
			LS	LF
	Midship Section			
A4	Shell Expansion	4,5	9,5	14
A5	Frame Section	14	14	19
A6	MTO (Material Take Off)	4	19	23
B1	Procurement of Plate Requirements	30	23	53
B2	Procurement Machinery	45	188	233
B3	Procurement Electrical System	45	168	218
B4	Procurement Piping System	30	188	218
B5	Procurement Navigation & Communication System	30	225	255
B6	Procurement of Safety Equipment	15	240	255
B7	Procurement of Needs Interior & Exterior	15	233	248
C1	Making Nesting Plan	7	46	53
C2	Cutting Plate Requirements (With CNC)	60	53	113
C3	Process Sub Assembly	25	113	138
C4	Process Assembly	30	138	168
C5	Block Erection	45	168	213
D1	Process Keel Laying	0,5	257	257,5
E1	Installation Main Engine	3,5	249	252,5
E2	Installation Auxiliary Engine	5	213	218
E3	Propulsion Installation	2,5	252,5	255
E4	Installation Rudder	2,5	255	257,5
E5	Installation Navigation & Communication System	2,5	255	257,5
E6	Safety Equipment Installation	2,5	255	257,5
E7	Installation Requirements Interior And Exterior	7	248	255
F1	Pump Installation – Pumps	15	233	248
F2	Installation Piping System	30	218	248
F3	Installation Electrical System	30	218	248
G1	Pump Testing	2,5	255	257,5
G2	Testing Piping System	2,5	252,5	255
G3	Testing Electrical System	2,5	255	257,5
G4	Hull Welding Testing	6	245	251
G5	Tank Tightness Testing	4	245	249
G6	Window & Door Tightness Testing	2,5	255	257,5
G7	Inclining Test	1,5	253	254,5
G8	Dock Trial	1,5	254,5	256
G9	Sea Trial	0,5	256	256,5
G10	Testing Bollard Pull	1	256,5	257,5
H1	Launching	3,5	249	252,5
H2	Ship Handover	1,5	257,5	259

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Table 4 Total Calculation Results Float

Activity ID	Duration (Days)	Calculation Proceed		Countdown		Total Float
		ES	EF	LS	LF	
A1	3,5	0	3,5	2,5	1	2,5
A2	5	3,5	8,5	1	6	2,5
A3	3,5	8,5	12	6	9,5	2,5
A4	4,5	12	16,5	9,5	14	2,5
A5	5	16,5	21,5	14	19	2,5
A6	4	21,5	25,5	19	23	2,5
B1	30	25,5	55,5	23	53	2,5
B2	45	25,5	70,5	188	233	162,5
B3	45	25,5	70,5	168	218	147,5
B4	30	25,5	55,5	188	218	162,5
B5	30	25,5	55,5	225	255	199,5
B6	15	25,5	40,5	240	255	214,5
B7	15	25,5	40,5	233	248	207,5
C1	7	21,5	28,5	46	53	24,5
C2	60	55,5	115,5	53	113	2,5
C3	25	115,5	140,5	113	138	2,5
C4	30	140,5	170,5	138	168	2,5
C5	45	170,5	215,5	168	213	2,5
D1	0,5	215,5	216,5	257	257,5	41
E1	3,5	250,5	254	249	252,5	1,5
E2	5	215,5	220,5	213	218	2,5
E3	2,5	254	256,5	252,5	255	1,5
E4	2,5	256,5	259	255	257,5	1,5
E5	2,5	215,5	218	255	257,5	39,5
E6	2,5	215,5	218	255	257,5	39,5
E7	7	250,5	257,5	248	255	2,5
F1	15	215,5	230,5	233	248	17,5
	30	215,5	245,5	218	248	2,5
F3	30	220,5	250,5	218	248	2,5
G1	2,5	230,5	233	255	257,5	24,5
G2	2,5	245,5	248	252,5	255	7
G3	2,5	250,5	253	255	257,5	4,5
G4	6	215,5	221,5	245	251	29,5
G5	4	221,5	225,5	245	249	23,5
G6	2,5	257,5	260	255	257,5	2,5
G7	1,5	253	254,5	253	254,5	0
G8	1,5	254,5	256	254,5	256	0
G9	0,5	256	256,5	256	256,5	0
G10	1	256,5	257,5	256,5	257,5	0
H1	3,5	225,5	229	249	252,5	23,5
H2	1,5	257,5	259	257,5	259	0

The activities with zero total float are G7, G8, G9, G10, and H2. Thus, the critical path is G7–G8–G9–G10–H2.

Table 5 Calculation of Feeding Buffer

ID	Work Activities	Safe Duration (Days)	CCPM Duration (Days)	(S-A)/2	((S-A)/2)²
C5	Block Erection	90	45	22,5	506,25
G1	Pump Testing	5	2,5	1,25	1,5625
G2	Testing Piping System	5	2,5	1,25	1,5625
G3	Testing Electrical System	5	2,5	1,25	1,5625
G4	Hull Welding Testing	12	6	3	9
G5	Tank Tightness Testing	8	4	2	4
H1	Launching	7	3,5	1,75	3,0625
				Total	527
			Feeding Buffer (days)		45,91

Table 6 Calculation Project Buffer

ID	Work Activities	Safe Duration (Days)	CCPM Duration (Days)	(S-A)/2	((S-A)/2)²
G7	Inclining Test	3	1,5	0,75	0,5625
G8	Dock Trial	3	1,5	0,75	0,5625
G9	Sea Trial	1	0,5	0,25	0,0625
G10	Testing Bollard Pull	2	1	0,5	0,25
H2	Ship Handover	3	1,5	0,75	0,5625
			Total		2
			Project Buffer (days)		2,82

Table 7 Percentage of Zone Usage Buffer

Buffer Usage Zone	Project Buffer (Days)	Duration Used (Days)
0% - 33%	2,82	< 0,94
34% - 67%	2,82	0.94 to 1.88
68% - 100%	2,82	> 1,88

Table 8 Results of Labor Productivity Calculations

ID	Duration (*Days*)	Work Volume	Labor (*Man*)	Productivity (/*Mondays*)
A1	3,5	1 item	5	0,0571
A2	5	1 item	5	0,0400
A3	3,5	1 item	5	0,0571
A4	4,5	1 item	5	0,0444
A5	5	1 item	5	0,0400
A6	4	7 item	5	0,3500
B1	30	1 ls	5	0,0067

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ID	Duration (*Days*)	Work Volume	Labor (*Man*)	Productivity (/*Mondays*)
B2	45	1 ls	5	0,0044
B3	45	1 ls	5	0,0044
B4	30	1 ls	5	0,0067
B5	30	1 ls	5	0,0067
B6	15	1 ls	5	0,0133
B7	15	1 ls	5	0,0133
C1	7	1 ls	5	0,0286
C2	60	9107 kg	40	3,7946
C3	25	16328 kg	41	15,9298
C4	30	25071 kg	41	20,3829
C5	45	75216 kg	41	40,7675
D1	0,5	1 ls	39	0,0513
E1	3,5	2 unit	41	0,0139
E2	5	2 unit	41	0,0098
E3	2,5	2 unit	41	0,0195
E4	2,5	2 unit	41	0,0195
E5	2,5	1 ls	41	0,0098
E6	2,5	1 ls	41	0,0098
E7	7	1 ls	41	0,0035
F1	15	1 ls	41	0,0016
F2	30	1 ls	41	0,0008
F3	30	1 ls	41	0,0008
G1	2,5	1 ls	39	0,0103
G2	2,5	1 ls	39	0,0103
G3	2,5	1 ls	39	0,0103
G4	6	1 ls	39	0,0043
G5	4	1 ls	39	0,0064
G6	2,5	1 ls	39	0,0103
G7	1,5	1 ls	41	0,0163
G8	1,5	1 ls	6	0,1111
G9	0,5	1 ls	6	0,3333
G10	1	1 ls	39	0,0256
H1	3,5	1 ls	41	0,0070
H2	1,5	1 ls	5	0,1333
			Total	82,3662
			Average CCPM	2,0

Table 9 Results of Direct Labor Cost Calculation

No	Employee Type	Wage Cost/Day	Total TKL Cost
1	Project Manager	Rp630.360,00	Rp165.154.320,00
2	Project Leader	Rp528.360,00	Rp138.430.320,00
3	PPC Incharge	Rp481.440,00	Rp126.137.280,00
4	Engineering Incharge	Rp481.440,00	Rp126.137.280,00
5	Quality Control Incharge	Rp481.440,00	Rp126.137.280,00
6	HSE Incharge	Rp481.440,00	Rp121.322.880,00
7	Operator Forklift	Rp405.000,00	Rp89.302.500,00
8	Operator Crane	Rp405.000,00	Rp84.037.500,00
9	Sub Contractor	Rp6.422.625,00	Rp1.515.739.500,00
		Total Cost of TKL CCPM	Rp2.492.398.860,00

CCPM reduces activity durations, the productivity values change accordingly. The results are presented in Table 8.

8. Direct Labor Costs CCPM Scheduling

Direct labor costs for the X1 tugboat project were estimated using company guidelines, labor requirements, and daily wages based on an 8-hour workday. Under the CCPM scenario, wage adjustments were made in line with the assumed productivity increase, with increases of up to 50% of the normal wage. For example, the subcontractor's daily wage increased from Rp16,218.75 to Rp24,328.13. The complete calculation is presented in Table 9.

9. Comparative Analysis of Results

The results were compared across three indicators: project duration, labor productivity, and direct labor costs under the CCPM schedule versus the initial project condition.

a. Comparative Analysis of Project Duration

A comparison of project duration scheduling after using the CCPM method. The CCPM schedule reduces total project duration to 262 days, a reduction of 170 days or 39.35% from the initial 432-day schedule.

b. Comparative Analysis of Labor Productivity

Labor productivity was compared before and after applying CCPM. The CCPM schedule produces an average productivity of 2/Mondays, compared with 1/Mondays under the initial project condition, representing a 100% increase.

c. Comparative Analysis of Direct Labor Costs

The analysis evaluates the cost impact of implementing the CCPM schedule. The CCPM schedule increases direct labor costs by 0.14%, equivalent to Rp3,478,500.00. The increase results from the assumed 50% wage adjustment associated with the productivity improvement.

D. Conclusion

For the X1 tugboat new shipbuilding project, CCPM reduced the planned duration from 432 to 262 days, a reduction of 170 days or 39.35%. The analysis used a 50% reduction in safety time for each activity. The resulting schedule is therefore substantially shorter than the initial project schedule. Labor productivity increased from 1/Mondays to 2/Mondays under the CCPM schedule, representing a 100% increase. Direct labor costs increased by 0.14%, or Rp3,478,500.00, due to the assumed wage adjustments accompanying the productivity increase. A limitation of the study is the availability of detailed work-volume

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data for each activity. More complete activity-level data would strengthen future analyses.

Overall, the CCPM analysis indicates shorter scheduling, higher labor productivity, and a small increase in direct labor costs for this project. The approach may be considered for similar new shipbuilding projects when adequate production facilities and resources are available. Future studies should examine risk analysis, buffer management, and additional cost components within CCPM.

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